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PATENT APPLICATION

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Sir:

Transmitted herewith for filing under 37 CFR 1.53(b) is a(n): (X) Utility ( ) Design

(X) original patent application,

( ) continuation-in-part application

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INVENTOR(S): Thomas C. Anthony

TITLE: Magnetic Memory With Structures That Prevent Disruptions To Magnetization In Sense Layers

Enclosed are:

(X) The Declaration and Power of Attorney. (X) signed ( ) unsigned or partially signed

(X) 5 sheets of drawings (one set) ( ) Associate Power of Attorney

( ) Form PTO-1449 (X) Information Disclosure Statement and Form PTO-1449

( ) Priority document(s) ( ) (Other) (fee \$ )

## CLAIMS AS FILED BY OTHER THAN A SMALL ENTITY

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By

Typed Name: Dee Timmons

Respectfully submitted,

Thomas C. Anthony

By

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UNITED STATES PATENT APPLICATION FOR

**MAGNETIC MEMORY WITH STRUCTURES THAT  
PREVENT DISRUPTIONS TO MAGNETIZATION  
IN SENSE LAYERS**

Inventor:  
Thomas Anthony

**BACKGROUND OF THE INVENTION**

Field of Invention

5       The present invention pertains to the field of magnetic memories. More particularly, this invention relates to providing a magnetic memory with structures that prevent disruptions to magnetization in sense layers.

10      Art Background

15       A magnetic memory such as a magnetic random access memory (MRAM) typically includes an array of magnetic memory cells. Each magnetic memory cell usually includes a sense layer and a reference layer. The sense layer is usually a layer or film of magnetic material that stores magnetization patterns in orientations that may be altered by the application of external magnetic fields. The reference layer is usually a layer of magnetic material in which the magnetization is fixed or  
20      "pinned" in a particular direction.

25       The logic state of a magnetic memory cell typically depends on its resistance to electrical current flow. The resistance of a magnetic memory cell usually depends on the relative orientations of magnetization in its sense and reference layers. A magnetic memory cell is typically in a low resistance state if the overall orientation of magnetization in its sense layer is parallel to the orientation of magnetization in its  
30      reference layer. In contrast, a magnetic memory cell is typically in a high resistance state if the overall orientation of magnetization in its sense layer is anti-

parallel to the orientation of magnetization in its reference layer.

Typically, the overall magnetization pattern in the sense layer of a magnetic memory cell includes magnetization in its interior region and magnetization in its edge regions. In prior magnetic memory cells, demagnetization fields commonly present in the edge regions of the sense layer disrupt the overall orientation of magnetization in the sense layer from the desired parallel and antiparallel orientations. In addition, coupling fields and demagnetization fields from the reference layer can disrupt the magnetization of the sense layer from the desired parallel or antiparallel orientations. Such disruptions may manifest as undesirable magnetic domains.

Unfortunately, such disruptions to magnetization in the sense layer usually obscure the high and low resistance states of a magnetic memory cell, thereby making it difficult to determine the logic state of the magnetic memory cell during a read operation. In addition, the degree of disruption to sense layer magnetization may vary among the magnetic memory cells in an MRAM array and may vary between different MRAM arrays due to variation in the patterning steps and/or deposition steps of device manufacture. Such variation in the sense layer magnetization states usually leads to variations in the threshold switching field. Such variations in the threshold switching field typically produces uncertainty in MRAM write operations.

SUMMARY OF THE INVENTION

A magnetic memory cell is disclosed having a structure that prevents disruptions to the magnetization in the sense layer of the magnetic memory cell. In one embodiment, the structure includes a high permeability magnetic film that serves as a keeper for the sense layer magnetization. The keeper structure provides a flux closure path that directs demagnetization fields away from the sense layer. In another embodiment, the structure contains a hard ferromagnetic film that applies a local magnetic field to the sense layer in the magnetic memory cell.

The present techniques yield greater repeatability of magnetization characteristics among the magnetic memory cells in MRAM arrays. The structure has an additional advantage of enlarging the effective volume of the magnetic memory cell, thereby improving the thermal stability of the stored magnetization state. The structure also functions as an electromagnet to facilitate writing of the magnetic memory cells, thereby reducing MRAM power consumption.

Other features and advantages of the present invention will be apparent from the detailed description that follows.

**BRIEF DESCRIPTION OF THE DRAWINGS**

The present invention is described with respect to particular exemplary embodiments thereof and reference  
5 is accordingly made to the drawings in which:

**Figures 1a-1c** illustrate one embodiment of a structure for stabilizing a magnetic memory cell;

10 **Figure 2** shows one embodiment of the magnetic memory cell which is stabilized by a structure;

**Figures 3a-3b** show the "S" state and the "C" state, respectively, of the magnetization in a sense layer of a  
15 magnetic memory cell;

**Figure 4** is a top view of a magnetic memory, an MRAM, which incorporates the present teachings;

20 **Figures 5a-5e** illustrate process steps for forming the structures disclosed herein and the conductors of a magnetic memory;

**Figure 6** shows another alternative embodiment of a  
25 structure for stabilizing a magnetic memory cell;

**Figure 7** shows yet another alternative embodiment of a structure for stabilizing a magnetic memory cell.

**DETAILED DESCRIPTION**

5       **Figures 1a-1c** illustrate one embodiment of a structure 56 for stabilizing a magnetic memory cell 40. The structure 56 encases a conductor 20 which provides a path for electrical current flow during read and write operations on the magnetic memory cell 40.

10       **Figure 1a** shows a cross-sectional side view of the structure 56 and the magnetic memory cell 40 in a direction parallel to the length of the conductor 20. **Figure 1b** shows a cut-away top view of the structure 56 and the conductor 20 through the magnetic memory cell 40. Portions of the structure 56 overlap a pair of edge  
15       regions 157-158 of the magnetic memory cell 40. **Figure 1c** shows a perspective view of the structure 56 and the magnetic memory cell 40.

20       **Figure 2** shows one embodiment of the magnetic memory cell 40. The magnetic memory cell 40 includes a sense layer 50 that has an alterable magnetization state and a reference layer 54 having a pinned orientation of magnetization. In this embodiment, the magnetic memory cell 40 includes a tunnel barrier 52 between the sense  
25       layer 50 and the reference layer 54.

30       This embodiment of the magnetic memory cell 40 is a spin tunneling device in which an electrical charge migrates through the tunnel barrier 52 during read operations. This electrical charge migration through the tunnel barrier 52 occurs when a read voltage is

applied to the magnetic memory cell 40. In an alternative embodiment, a giant magneto-resistive (GMR) structure may be used in the magnetic memory cell 40 in which the tunnel barrier 52 is replaced with a conductor such as Cu.

In one embodiment, the structure 56 serves as a keeper for the sense layer 50 magnetization and may be referred to as the keeper structure 56. The keeper structure 56 is a soft magnetic material that provides a mechanism for flux closure, thereby preventing the formation of demagnetization fields in the edge regions 157-158. The keeper structure 56 is a high permeability ferromagnetic film that is magnetized with an easy axis substantially perpendicular to the easy axis of the sense layer 50 of the magnetic memory cell 40. The proximity of the keeper structure 56 to the magnetic memory cell 40 causes any demagnetization fields that would have been produced in the absence of the keeper structure 56 to be directed through the keeper structure 56. This provides a path for flux that substantially eliminates demagnetizing fields from acting on the sense layer 50 in the magnetic memory cell 40. This prevents the overall magnetization in the sense layer 50 of the magnetic memory cell 40 from straying from the desired parallel or antiparallel directions with respect to the pinned reference layer 54 in the magnetic memory cell 40. The keeper structure 56 stabilizes the magnetic memory cell 40 in that it provides a pair of stable and discernable high and low resistance states for storing a data bit.



The keeper structure 56 reduces the electrical current level needed to write the magnetic memory cell 40 to a desired logic state. The keeper structure 56 is analogous to a single-turn electromagnet. Electrical current flowing through the conductor 20 rotates the magnetization of the keeper structure 56 from its quiescent state along its length to a direction perpendicular to the direction of electrical current flow according to the right hand rule. This creates a magnetic field along the easy axis of the sense layer 50 in the magnetic memory cell 40 which is useful for rotating the magnetization in the sense layer 50 to either the parallel or antiparallel state with respect to the pinned reference layer 54 of the magnetic memory cell 40.

A reduction in the electrical current level needed to write the magnetic memory cell 40 is desirable because it reduces power consumption in a magnetic memory such as an MRAM. A reduction in power consumption is particularly advantageous for portable applications. In addition, a reduction in the electrical current level needed to write the magnetic memory cell 40 reduces the integrated circuit chip area consumed by the power transistors that supply write currents. The chip area savings lowers the cost of a magnetic memory.

The keeper structure 56 obviates the need to reduce the thickness of the sense layer 50 in the magnetic memory cell 40 or to increase or elongate the  $d_x$  and  $d_y$  dimensions of the magnetic memory cell 40 in an attempt to reduce the effects of demagnetization fields in the

sense layer 50. This enables magnetic memories to be formed with thicker sense layers which increases the thermal stability of the magnetic memory by increasing the magnetic volume of the magnetic memory cell 40 and enhances uniformity in the switching behavior among the magnetic memory cells of a magnetic memory. This also enables the formation of magnetic memory cells with smaller  $d_x$  and  $d_y$  dimensions which increases the data storage density of a magnetic memory. In addition, the keeper structure 56 itself adds effective magnetic volume to the magnetic cell 40 which increases the thermal stability of the stored magnetization state.

In one embodiment, the dimensions  $d_x$  and  $d_y$  of the magnetic memory cell 40 are selected to be substantially equal and form a square shape for its sense layer 50. The square shape of the sense layer 50 enhances the density that may be obtained in an MRAM in comparison to that which may be obtained when using rectangular memory cells. This is so because for a given minimum feature size more square magnetic memory cells may be formed on a given substrate area than rectangular magnetic memory cells. In other embodiments, rectangular or other shapes may be used.

The sense layer 50 or the reference layer 54 may be directly exchange coupled to the keeper structure 56 or magnetically decoupled from the keeper structure 56 by spacer layers.

In one embodiment, the magnetic memory cell 40 is positioned so that the sense layer 50 is adjacent to the keeper structure 56. The sense layer 50 is directly

exchange coupled to the keeper structure 56 at the edge regions 157 and 158. The sense layer 50 is influenced by the magnitude and direction of the magnetic anisotropy of the keeper structure 56.

5

**Figures 3a-3b** show the "S" state and the "C" state, respectively, of the magnetization in the sense layer 50. Since the easy axis of the keeper structure 56 lies along the length of the conductor 20, the sense layer 50 has a local exchange field applied to the edge regions 157 and 158 that is perpendicular to the easy axis of the sense layer 50. Application of this orthogonal field in the edge regions 157 and 158 forces the sense layer 50 magnetization to be in a "S" state as opposed to an "C" state. The "S" state may have more reproducible switching characteristics.

Alternatively, the magnetic memory cell 40 is flipped over so that the reference layer 54 is adjacent to the keeper structure 56. The sense layer 50 is not exchange coupled to the keeper structure 56 but is influenced by the proximity of the permeable keeper structure 56 and no orthogonal field is generated in the edge regions 157-158.

25

**Figure 4** is a top view of a magnetic memory 10, an MRAM, which incorporates the present teachings. The magnetic memory 10 includes an array of magnetic memory cells including the magnetic memory cell 40 along with additional magnetic memory cells 41-43. The magnetic memory 10 includes an arrangement of conductors 20-21

30

and 30-31 that enable read and write access to the magnetic memory cells 40-43.

5           The conductors 30-31 are top conductors and the  
conductors 20-21 are orthogonal bottom conductors  
encased in corresponding structures 56-57. The  
conductor 20 provides a bottom conductor for both  
magnetic memory cells 40 and 42 and the structure 56  
provides a structure for both magnetic memory cells 40  
10   and 42. Similarly, the conductor 21 provides a bottom  
conductor for both magnetic memory cells 41 and 43 and  
the structure 57 provides a structure for both magnetic  
memory cells 41 and 43.

15           The structures 56 and 57 are each magnetized with  
an easy axis that is substantially parallel to the y  
axis. The easy axes of the sense layers in the magnetic  
memory cells 40-43 are substantially parallel to the x  
axis. Electrical current flowing through the conductor  
20   20 creates magnetic writing fields which are parallel to  
the x axis and parallel to the easy axes of the sense  
layers in the corresponding magnetic memory cells 40 and  
42. Similarly, electrical current flowing through the  
conductor 21 creates magnetic writing fields parallel to  
25   the easy axes of the sense layers in the corresponding  
magnetic memory cells 41 and 43. Electrical current  
flow through the conductor 30 or 31 generates a magnetic  
field in the y direction. Only the magnetic memory  
cells that experience a combination of x and y magnetic  
30   fields are written.

Figures 5a-5e illustrate process steps for forming the structures 56-57 and the conductors 20-21 of the magnetic memory 10. The magnetic memory 10 is formed on a substrate 100 (Figure 5a) which in one embodiment is a dielectric such as silicon-dioxide ( $\text{SiO}_2$ ).

A set of trenches 102-104 (Figure 5b) are formed in the substrate 100. The trenches 102-104 may be formed using, for example, reactive ion etching.

Next, a stabilization layer 106 (Figure 5c) is deposited on the substrate 100 and its trenches 102-104. The stabilization layer 106 is a layer of ferromagnetic material which may be a soft magnetic material such as nickel-iron (NiFe) in a keeper structure embodiment or hard material such as CoPt, CoPtCr, or CoPtTa in the alternative embodiment. The stabilization layer 106 is preferably deposited using a technique such as sputtering which coats both horizontal and vertical surfaces of the substrate 100 and its trenches 102-104.

A layer of conductor material 108 (Figure 5d) such as copper is then deposited on the stabilization layer 106. The conductor material 108 may be deposited using sputtering, evaporation, or plating steps.

A chem-mechanical polishing (CMP) step is then applied to planarize the surface and expose the substrate 100 (Figure 5e).

The layers of the magnetic memory cells 40-43 are then deposited on the polished surface of the substrate 100 and patterned over the structures 56-57. The layers for the magnetic memory cells 40-43 in one embodiment include the following. First, a set of seed layers of tantalum, nickel-iron, and iron-manganese are deposited. Next, a layer of nickel-iron is deposited which serves as the reference layers of the magnetic memory cells 40-43. A dielectric layer such as aluminum-oxide ( $Al_2O_3$ ) is then deposited which serves as the tunnel barriers within the magnetic memory cells 40-43. Next, a layer of nickel-iron is deposited which is to be patterned into the sense layers of the magnetic memory cells 40-43. Finally, tantalum is deposited as an encapsulating layer.

In an alternative embodiment of a structure for stabilizing a magnetic memory cell 40, the structure 56 is a hard ferromagnetic material that is magnetized along the length of the conductor 20, a direction that is substantially perpendicular to the easy axis of the sense layer 50. In this alternative embodiment, the structure 56 does not function as a keeper but is instead a source of magnetic field for stabilizing the edge regions 157 and 158. The structure 56 is directly exchange coupled to the under side of the sense layer 50. As a result, the longitudinally magnetized hard magnetic material of the structure 56 interacts with the sense layer 50. Such an exchange coupled configuration generates the desired "S" state in the magnetization of the sense layer 50 by forcing the magnetization in the edge regions 157 and 158 to be aligned parallel to the direction of magnetization of the structure 56.

Exchange coupling the sense layer 50 to the structure 56 forces the magnetization into the "S" state.

**Figure 6** shows another alternative embodiment of a structure for stabilizing a magnetic memory cell 40. In this alternative embodiment, the structure 56 is a soft magnetic film of uniform thickness which is patterned to substantially the same width as the conductor 20. The magnetization of the structure 56 lies parallel to the length of the conductor 20 and substantially perpendicular to the easy axis of the sense layer 50. The soft magnetic film that forms the structure 56 may be located anywhere through the thickness of the conductor 20. The total thickness of the conductor 20 is  $t$  which is equal to  $t_1 + t_2$  and the position of the structure 56 can range from  $t_1=0$  to  $t_2=0$ .

**Figure 7** shows another alternative embodiment of a structure for stabilizing the magnetic memory cell 40. In this alternative, the keeper structure 56 is inverted in comparison to the embodiment shown in **Figures 1a-1c**. A thin layer 200 of, for example, tantalum lies between the keeper structure 56 and the magnetic memory cell 40. The magnetization of the keeper structure 56 lies parallel to the length of the conductor 20 and substantially perpendicular to the easy axis of the sense layer 50.

The foregoing detailed description of the present invention is provided for the purposes of illustration and is not intended to be exhaustive or to limit the invention to the precise embodiment disclosed.

Accordingly, the scope of the present invention is defined by the appended claims.

[illegible]



CLAIMS

What is claimed is:

- 5     1.    A magnetic memory cell, comprising:  
          sense layer for storing a magnetization state that  
          indicates a logic state of the magnetic memory cell;  
          structure that prevents disruptions to the  
          magnetization state in the sense layer.
- 10           2.    The magnetic memory cell of claim 1, wherein the  
          structure overlaps a pair of opposing edge regions of  
          the sense layer and prevents one or more demagnetization  
          fields from forming in the edge regions of the sense  
15           layer.
3.    The magnetic memory cell of claim 1, wherein the  
          structure is formed from a permeable ferromagnetic  
          material having a shape that provides flux closure for  
20           one or more demagnetization fields in the sense layer.
4.    The magnetic memory cell of claim 1, wherein the  
          structure is formed from a permeable ferromagnetic  
          material having an easy axis that is perpendicular to an  
25           easy axis of the sense layer.
5.    The magnetic memory cell of claim 1, wherein the  
          structure encases a conductor that provides read and  
          write access to the magnetic memory cell.
- 30           6.    The magnetic memory cell of claim 1, further  
          comprising a reference layer and a tunnel barrier  
          between the sense layer and the reference layer.

7. The magnetic memory cell of claim 6, wherein the sense layer is adjacent to the structure.

8. The magnetic memory cell of claim 6, wherein the  
5 reference layer is adjacent to the structure.

9. The magnetic memory cell of claim 1, wherein the sense layer is exchange coupled to the structure.

10 10. The magnetic memory cell of claim 1, wherein the structure is formed from a hard ferromagnetic material.

11. The magnetic memory cell of claim 10, wherein the hard ferromagnetic material is magnetized perpendicular  
15 the an easy axis of the sense layer.

12. The magnetic memory cell of claim 10, wherein the sense layer is exchange coupled to the structure.

20 13. A magnetic memory cell, comprising:  
sense layer for storing a magnetization that indicates a logic state of the magnetic memory cell;  
means for providing flux closure for one or more demagnetization fields in the magnetic memory cell.

25 14. The magnetic memory cell of claim 13, wherein the means for providing flux closure comprises a permeable ferromagnetic material having a shape that provides a path for magnetic flux transport between a pair of  
30 opposing edge regions of the sense layer.

15. The magnetic memory cell of claim 14, wherein the permeable ferromagnetic material has an easy axis that is perpendicular to an easy axis of the sense layer.

- 5 16. A method for forming a magnetic memory with a set of structures, comprising the steps of:

forming a set of trenches in a substrate;

depositing a layer of magnetic material for the structures so that the magnetic material coats

- 10 horizontal and vertical surfaces of the trenches and the substrate;

depositing a layer of conductor material on the layer of magnetic material to fill the trenches;

- 15 polishing the layer of conductor material and the layer of magnetic material to expose an upper surface of the substrate.

17. The method of claim 16, wherein the conductor material is copper.

20

18. The method of claim 16, wherein the step of polishing comprises the step of polishing using a chem-mechanical process.

- 25 19. The method of claim 16, wherein the step of forming a set of trenches comprises the step of forming a set of trenches using reactive ion etching.

- 30 20. The method of claim 16, further comprising the steps of:

depositing a material for a sense layer in each of a set of magnetic memory cells in the magnetic memory;

depositing a material for a tunnel barrier in each of the magnetic memory cells;

depositing a material for a reference layer in each of the magnetic memory cells.

5

21. The method of claim 16, wherein the material for the sense layer is deposited before the materials for the tunnel barrier and reference layers.

10

22. The method of claim 21, wherein the material for the reference layer is deposited before the materials for the tunnel barrier and sense layers.

ABSTRACT

A magnetic memory cell is disclosed having a structure that prevents disruptions to the magnetization in the sense layer of the magnetic memory cell. In one  
5 embodiment, the structure includes a high permeability magnetic film that serves as a keeper for the sense layer magnetization. The keeper structure provides a flux closure path that directs demagnetization fields away from the sense layer. In another embodiment, the  
10 structure contains a hard ferromagnetic film that applies a local magnetic field to the sense layer in the magnetic memory cell.



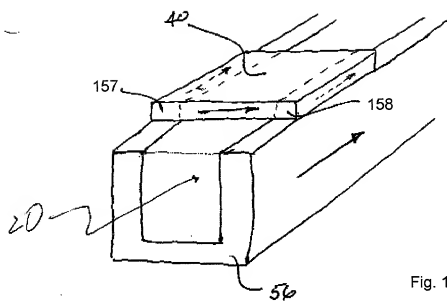


Fig. 1c

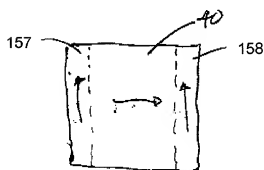


Fig. 3a

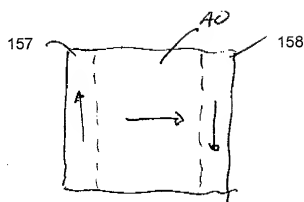
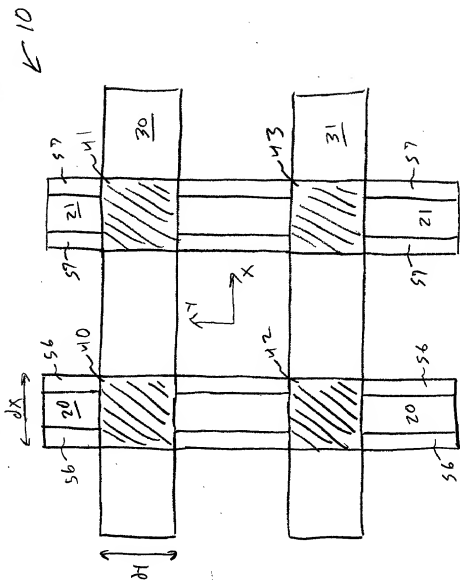


Fig. 3b



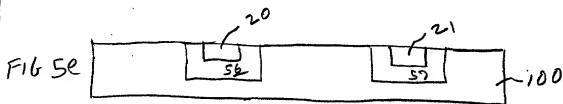
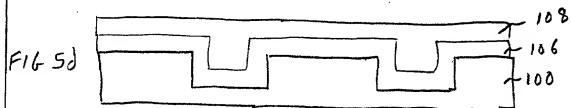
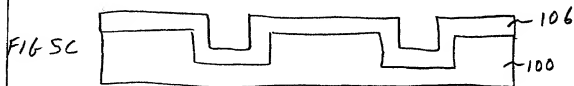
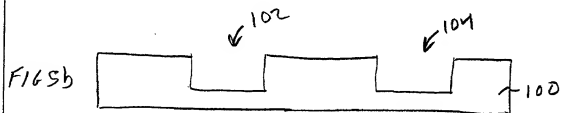
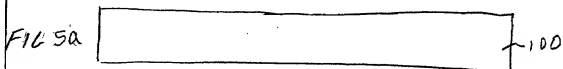
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FIG 4



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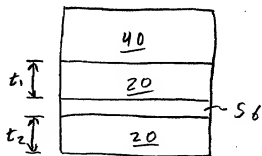


FIG. 6

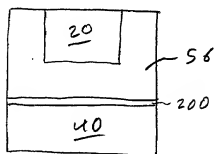


FIG. 7

DECLARATION AND POWER OF ATTORNEY  
FOR PATENT APPLICATIONATTORNEY DOCKET NO. 10990034-1

As a below named inventor, I hereby declare that:

My residence/post office address and citizenship are as stated below next to my name;

I believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled:

**Magnetic Memory With Structures That Prevent Disruptions To Magnetization In Sense Layers**

The specification of which is attached hereto unless the following box is checked:

( ) was filed on \_\_\_\_\_ as US Application Serial No. or PCT International Application Number \_\_\_\_\_ and was amended on \_\_\_\_\_ (if applicable).

I hereby state that I have reviewed and understood the contents of the above-identified specification, including the claims, as amended by any amendment(s) referred to above. I acknowledge the duty to disclose all information which is material to patentability as defined in 37 CFR 1.56.

**Foreign Application(s) and/or Claim of Foreign Priority**

I hereby claim foreign priority benefits under Title 35, United States Code Section 119 of any foreign application(s) for patent or inventor(s) certificate listed below and have also identified below any foreign application for patent or inventor(s) certificate having a filing date before that of the application on which priority is claimed:

COUNTRY	APPLICATION NUMBER	DATE FILED	PRIORITY CLAIMED UNDER 35 U.S.C. 119
			YES: _____ NO: _____
			YES: _____ NO: _____

**Provisional Application**

I hereby claim the benefit under Title 35, United States Code Section 119(e) of any United States provisional application(s) listed below:

APPLICATION SERIAL NUMBER	FILING DATE

**U. S. Priority Claim**

I hereby claim the benefit under Title 35, United States Code, Section 120 of any United States application(s) listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States application in the manner provided by the first paragraph of Title 35, United States Code Section 112, I acknowledge the duty to disclose material information as defined in Title 37, Code of Federal Regulations, Section 1.56(a) which occurred between the filing date of the prior application and the national or PCT international filing date of this application:

APPLICATION SERIAL NUMBER	FILING DATE	STATUS (patented/pending/abandoned)

**POWER OF ATTORNEY:**

As a named inventor, I hereby appoint the following attorney(s) and/or agent(s) to prosecute this application and transact all business in the Patent and Trademark Office connected therewith:

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Number Bar Code  
Label here**Send Correspondence to:**HEWLETT-PACKARD COMPANY  
Intellectual Property Administration  
P.O. Box 272400  
Fort Collins, Colorado 80528-9599**Direct Telephone Calls To:**Timothy R Croll  
(650) 857-4881

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

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Inventor's SignatureJan. 27, 2000  
Date